

POSSIBILITIES TO VERIFY THE LEVEL DENSITY AND RADIATIVE STRENGTH FUNCTIONS, EXTRACTED FROM THE TWO-STEP γ -CASCADE INTENSITIES

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1 Introduction

The direct determination of density ρ of excitation levels (number of levels of nucleus in the unit interval of excitation energy) for the larger part of stable and long-life radioactive target nuclei is impossible. This assertion relates also to the radiative strength functions

$$k = \Gamma_{\lambda i} / (E_{\gamma}^3 \times A^{2/3} \times D_{\lambda}) \quad (1)$$

exciting their primary dipole electrical and magnetic gamma-transitions of level of nucleus decaying the excited in the nuclear reaction. This circumstance is uniquely determined by the fact, that D_{λ} is much less than the resolution of the existing spectrometers of gamma-rays and charged particles or neutrons. Extraction of the parameters of nucleus in question in this situation can be executed by only their fitting to the optimum values, reproducing the spectra and cross section with the minimum standard deviation measured in the nuclear reactions.

This inverse problem of mathematical analysis by its nature is principally ambiguous. Moreover, systems of equations, connecting the number of excited levels and probability of the emission of nuclear products are usually assigned within the framework of some ideas about the mechanism of nuclear reaction and factors determining the dynamics of the studied process.

Thus, for example, the description of the cascade gamma-decay of neutron resonance, is impossible at present without the introduction of some a priori ideas. In particular, within the framework of the ideas about this process following potential possibilities are not taken into consideration:

the presence of the strong dependence of neutron widths Γ_n^0 on the structure of the wave function of resonances (and of the excessive error in determination of their density by the time-of-flight method),

the analogous dependence of the partial radiative widths of primary gamma-transitions on the structure of the level excited by them, evidently overstepping the limits of the expected Porter- Thomas fluctuations;

The possibility of existence of the enumerated effects and their sufficiently their significant influence on the process of cascade gamma-decay directly follows from the results [1] of model approximation of the level density, extracted from the reaction $(n, 2\gamma)$ and the comparison [2,3] of the average values of the sums of radiative strength functions with

their models [4,5] most often used in practice. Thus, the break of sequential Cooper pair [1] with the excitation energy in the region of the neutron-binding energy can change values of one (two) quasi-particle components in the wave function and thus - change [6] values of Γ_n^0 . This possibility directly follows from the results, presented in [1]. Whether this possibility is realizable in principle, to what degree the process of fragmentation of nuclear states mixes up components of different types in the wave functions of the levels in the region $E_{ex} \geq B_n$ and at the noticeably higher excitation energies - neither the experiment, nor the theory can answer this at the present.

In particular it is not possible to obtain the realistic estimation of the part of the unobservable levels, which according to the values J^π could be excited them as s-resonances. This problem is very essential, since the density of neutron resonances in practice in any experiment to determine this parameter for the excitation lower than B_n is used to standardize its relative values. As a consequence of the above mentioned facts, the measured experimentally in different procedures [2,3,7,8] level densities and the radiative strength functions of primary gamma-transitions can have an unknown systematic error, the value of which directly depends on a systematic error in the conventional values D_λ of the spacing between the neutron resonances. And the obtained ideas about these values and properties of nucleus can be erroneous to a greater or lesser extent. However, if we add the fundamental incompatibility of the data about the level density between the results of applying the procedures [7,8] on the one hand, and [2,3] on the other hand, than the need for a maximally possible verification of ρ and k determined from indirect experiments becomes obvious.

2 Possibilities and the specific character of the verification of the experimentally determined values of ρ and k

The verification of the indicated parameters of nucleus can be partially executed by the calculation of total gamma-spectra for different sets of ρ and k with their subsequent comparison with the experiment. This calculation was carried out by different authors repeatedly [9,10], but, as a rule, without taken into account of:

- the nonconformity of the model assigned ones and real values of ρ or k if to determine one of these values purely model presentations about another value are used;

- the specific character of the transfer of errors $\delta\rho$ and δk to an error of the calculated spectrum;

- all aspects of the influence of the structure of the excited levels of nucleus on the parameters ρ and k .

All these problems become apparent to the full during the calculation of the gamma-ray spectra of the radiative capture of thermal neutrons, measured, for example, by Groshev [11], with the use of ρ and k , determined from the gamma-ray intensities in the procedures [8] or [2,3]. The major part of experimental data on the total gamma-ray spectra of the capture not only of thermal but also fast neutrons was used to verify such data earlier [12]. At present, maximally reliable data on to the level density and the radiative strength functions of primary and secondary gamma-transitions are acquired [2,3] for the isotopes

^{183,184,185,187}W. They describe precise not only the intensities of two-step cascades and the total radiative widths of the compound-states of these nuclei, but also, to the maximum degree - the cascade population of their levels up to the excitation energy 3-4 MeV. Noticeably less reliable (because of low efficiency of the used spectrometer) Values ρ and k are determined also for the isotopes ^{163,164,165}Dy [2,3,13].

The corresponding total gamma-ray spectra are determined by the enumerated isotopes for 88% in Dy and practically for 100% - in W. Due to the absence of data on the level density and radiative strength functions extracted from the cascade intensities for the compound nucleus of ¹⁶²Dy, the missing 12% are completed by the total gamma-spectrum of ¹⁶⁴Dy. This is done on the basis of the observation of insubstantial divergence in the calculated total gamma-spectra of odd isotopes and extrapolation of this fact to the even isotopes of dysprosium.

3 The comparison of calculation and experiment

It is most expedient to perform the comparison of total gamma-spectra for the spectrum corresponding to the product of the gamma-quantum intensity on their energy. The condition $\sum I_\gamma E_\gamma = B_n$ ensures the maximally precise normalization intensities of the observed gamma-transitions on the average and the presence of errors of different sign - for different values of gamma-quantum energies. For the spectrum determined in [11] during the capture of thermal neutrons in the target of natural isotopic composition the normalization is carried out for the sum of neutron-binding energy the weighted on the part of captures in all the isotopes. For Dy and W it is equal 6104 and 5770 keV, respectively, and is determined by the target isotopes ¹⁶⁴Dy and ¹⁸⁶W dominating in the capture .

The sums of the level densities of both parities and spins 1/2 and 3/2 for these compound nuclei are given in Fig. 1; the sums of the radiative strength functions of primary gamma-transitions with the coefficients of an increase in the radiative strength functions of secondary transitions are given in Fig. 2 respectively. The calculated total gamma-spectra of the capture of thermal neutrons in the SAMPLE of natural isotopic composition are compared with the experiment in Fig. 3. The real resolution of the Groshev's experiment was considered at their calculation. Also in the distributions of the cascade intensities determined in the experiment with the threshold of the registration of 520 keV the cascades are added corresponding in the observed intensity to the strongest primary gamma-transitions to the ground and one or two low-lying levels.

This procedure changes very weakly the parameters of sets ρ and $k(E1) + k(M1)$, of those determined accordingly [2,3], but it allow one to exclude the high-energy part of the total gamma-spectra with their maximum fluctuations from the comparison. Practically, this leads to reduction of the area of low-energy ($E_\gamma < 5$ MeV) part of the area of the calculated spectrum less, than 5%. An error in the determination of total gamma-spectra can be estimated from the comparison of the intensities of the same transitions with the contemporary data [14]. It cannot be less than 10-20%.

The results of the comparison of the spectra, calculated for different functional dependencies of level density and sums of the strength functions of dipole gamma-transitions with the experiment, quite unambiguously lead to the conclusion, fully coinciding with those obtained earlier:

“smooth” function $\rho = f(E_{ex})$ reproduces the total gamma-spectrum of the thermal neutron capture noticeably worse, than the stepped functional dependencies obtained in [2,3];

in the well deformed dysprosium taking into account various forms of the energy dependence of the radiative strength functions of primary and secondary transitions substantially improves the quality of this description. Moreover the degree of the dependence $k(E1) + k(M1)$ on the energy of the secondary transition is less than in the primary one. In tungsten because of the smaller divergence of the form of the experimental spectrum and the calculated one similar calculations are differ less.

The same picture is also observed for the pairs of ρ and $k(E1) + k(M1)$, reproducing only the cascade intensities and, simultaneously, the cascade population of levels below 3-4 MeV.

A more detailed analysis of deviation of the calculated spectrum from the experimental one for tungsten shows, that the degree of description of the difference between the functional dependencies of the radiative strength functions of primary and secondary gamma-transitions requires more precise definition and detailing. However, to do this is only possible after obtaining additional information about the intensities of cascades. Large coefficients of the transfer of the errors of total gamma-spectrum to the errors of $\delta\rho$ and $\delta(k(E1) + k(M1))$ do not make it possible using data of fig. 3 only. In particular, taking into account the influence of the structure of the excited levels on a change in the form of the energy dependence of radiative strength functions most likely should be carried out up to the neutron binding energy. One must not exclude the possibility that the radiative and neutron strength functions also depend on the structure of neutron resonances at the excitation energies larger, than B_n .

4 Conclusion

The comparison of the total gamma-spectra for different functional dependencies of ρ and $k(E1) + k(M1)$ both on the excitation energy of nucleus and on the energies corresponding to the primary and secondary gamma-transitions for the thermal neutrons capture in Dy and W with the experimental data was carried out.

It showed that model predictions of the non interacting Fermi gas in these nuclei give worse correspondence, than the level density from the procedures [2,3]. This conclusion totally corresponded to the one obtained earlier [12].

Large transfer coefficients of the errors of total gamma-spectra to the errors $\delta\rho$ and $\delta(k(E1) + k(M1))$ directly follow from the comparison of the data in Figs. 1,2 and 3. This circumstance confirms the conclusion [1], that the measurement of such spectra, for example in the procedure [8], requires accuracy on ~ 2 orders larger, than in the procedure [2,3]. And it limits the possibilities of the independent checking of different sets of ρ and k , both of model determined ones and of experimentally obtained ones. The use of total gamma-spectra for their testing necessary requires the comparison of different variants of such data.

And even total reproduction of the experimental total gamma-spectrum by calculation with a certain set of ρ and k is not the proof of the correspondence of these values to the real parameters of nucleus. However, explicit nonconformity is a quite single-valued proof

of the presence of larger or smaller systematic deviation for them with the experimental one.

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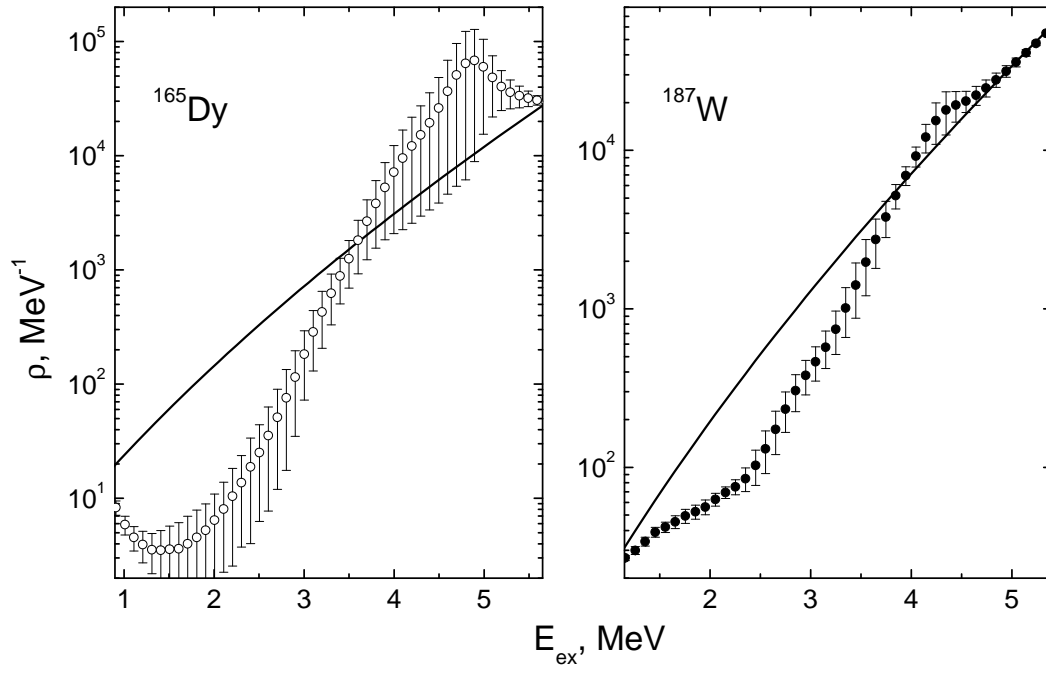


Fig. 1. The interval of probable values of the level density enabling the reproduction of the experimental cascade intensity (as a function of primary transition energy) and total radiative width of capture state. The line represents predictions of the model [15].

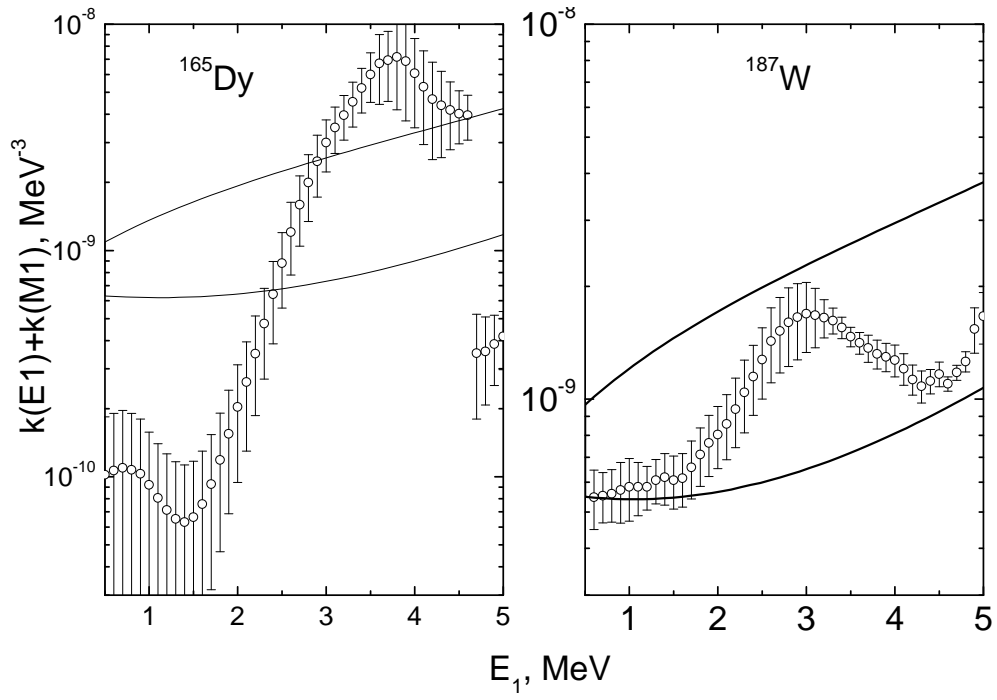


Fig. 2. The probable interval of the sum strength function $k(E1) + k(M1)$ (points with error bars) providing the reproduction of the experimental data. Solid line is predictions of models [4,5].

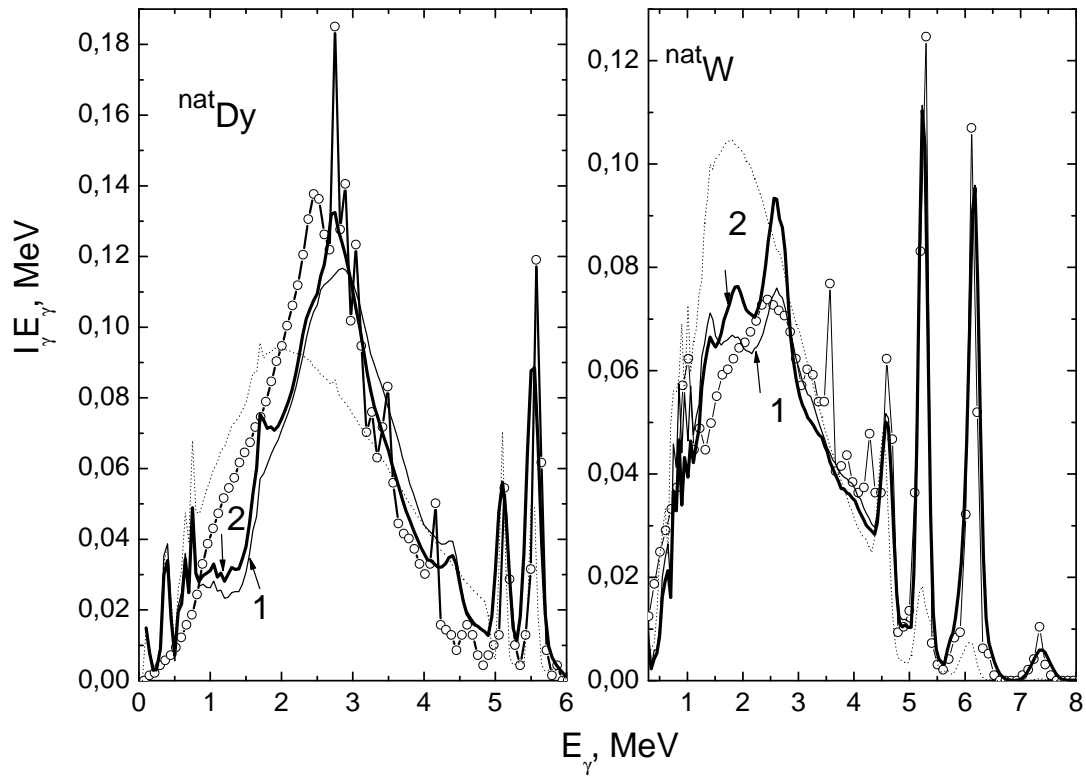


Fig. 3. The experimental (points) total spectra of γ -radiation following thermal neutron capture for the ^{nat}Dy and ^{nat}W targets. Solid and dashed lines represent results of calculation using data [2,3] and model parameters [4,5,15], respectively. Line 1 calculated with ρ and k parameters from [3], line 2 - from [2], corresponding.